A Study of Inflation of the Lungs of the Newborn

A Preliminary Report

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SUMMARY

There seems to be no reasonable doubt that the lungs in a newborn expand progressively during the first few days of life. Some degree of atelectasis seems to be perfectly normal. This is indicated by a number of roentgenographic studies (including those here reported); by the reported findings of pathologists; by the fact that in experimental animals the lungs inflated very unevenly; and by the fact that aeration of only a portion of the lung is needed for complete oxygenation of the blood. The relation of atelectasis to neonatal death is not entirely clear and is probably not always the same. The infant may die from other causes before the lungs are fully expanded. Atelectasis may develop secondarily to other debilitating conditions. The frequent coincidence of prematurity and extensive atelectasis is impressive. It may be that the lungs are so incompletely formed that they cannot expand. On the other hand, atelectasis and massive collapse in the adult is a serious condition and there seems to be no good reason to suppose that this cannot also occur in infants and be serious per se.

The air pressures found necessary to expand the lungs in rabbit fetuses were found to be about ten times what adult humans use in quiet respiration and were of about the same magnitude as the pressures found necessary to expand the lungs of stillborn humans. An attempt to produce atelectasis in newborn rabbits by chilling was most inconclusive. Atelectasis did develop in three of 15 animals used in the experiment, but the relation to chilling was not at all clear.

AN obstetrician in Duluth made a study of stillbirths and neonatal deaths at Duluth hospitals over a period of 20 years. He found that the deaths from all causes had decreased materially during the 20 years, with two exceptions, namely, atelectasis of the lungs and malformations and abnormalities incompatible with life. A group of six physicians* decided to make a study of atelectasis. Three questions were posed: (1) Is atelectasis the cause of death in these infants? (2) Does premedication given to the mother favor atelectasis in the infant? (3) Is atelectasis after birth normal? The group has answered none of these questions, with the possible exception of the last one, and the problem, for the time being, has resolved itself into the study of the physiological expansion of the lungs in the newborn. This is merely a preliminary report of part of what the group is attempting to do.

A study of the literature indicates that many others have faced these questions and that, as yet, observers are not entirely agreed upon the answers.

Beck[1] reported upon 200 stillbirths and neonatal deaths in which 41.5 per cent showed nothing more than congenital atelectasis. Labate,[8] in an analysis of the causes of death in a group of 868 stillborns and neonatal deaths, listed pulmonary lesions as one of the three highest causes of death, but did not mention atelectasis among them. Bell[2] has expressed the opinion that atelectasis is not the cause of death in most infants showing this condition, but is merely an indication of weakness and debility secondary to other conditions which may cause death.

Potter and Dieckmann[10] reported upon a group of 17,500 infants with 25 deaths per thousand, equally divided between stillbirths and neonatal deaths. Twenty-five per cent of these deaths were assigned to prematurity and, in these infants, the lungs were almost invariably red-purple in color, uniformly firm in consistency and so airless that they sank in water. Microscopically, they usually revealed resorption atelectasis. Most of these infants had breathed promptly after birth but, within a few hours, gave evidence of respiratory distress. They became progressively more cyanotic, even when kept in oxygen, and finally died of respiratory failure. This picture was almost always limited to infants weighing less than 2,500 gm.

Wilson and Farber[13] did some excellent experimental work on the lungs of stillborn children and those dying shortly after birth, as well as on the lungs of living and dead animals. They concluded that atelectasis of the newborn should not be considered as a primary cause of death and that there must be some cause for the persistence of atelectasis. They found that a relatively great force is required to open the lungs the first time and decided that this resistance to expansion was due to cohesion of the moist surfaces of the collapsed air passages and the alveoli. They found that once the initial resistance

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was overcome, the lungs expanded with a much lower pressure. The initial resistance could be reestablished by aspirating the lungs forcibly or by allowing them to hang for a number of hours. They pointed out that there is another type of atelectasis which is due to incomplete development of the lungs. They found that pressure of as much as 350 mm. of water might be required to produce full distention of the lungs in stillborn babies. (Adults use a force of only 10 to 20 mm. in quiet respiration.)

Smith[11] found that pressure of 300 mm. of water may be necessary for expansion. He stated that some degree of atelectasis may be demonstrable in normal infants for a week after birth. Potter and Adair[9] also expressed the belief that aeration of the lungs in a normal newborn is gradual.

Gruenwald[6] differentiated three states of fetal lungs, namely, aeration, atelectasis and a third, which he called fluid-containing. He expressed belief that fetal atelectasis is a normal state of the lungs just before birth. He reported that true atelectasis is much more common in live-born than in stillborn children, and that the lungs of stillborns are much more apt to contain fluid because, in a period of anoxia, they have attempted to breathe in utero. Gruenwald measured the resistance of the lung tissue to expansion with both air and a watery fluid and found that the lungs expanded at a much lower pressure when fluid was used than when air was used. There was a more uniform expansion of the alveoli with fluid than with air. With the latter, expansion was not uniform: Some alveoli expanded fully and others not at all. There was no intermediate stage. The author studied 30 stillborn infants and 30 newborn infants up to three days of age. He found that live-born infants showed much less aspiration of amnionic fluid than the stillborns. He found commonly that some of the alveoli would be aerated while others were partially expanded with fluid.

Zettelman[14] agreed, after some experimental studies on animals, that complete atelectasis of the lungs is maintained until birth unless there is some degree of anoxia. Amnionic fluid is present normally in the larger air passages but is not normally present in the alveoli.

Farber and Wilson,[3] reviewing the literature concerning the nature of atelectasis in the newborn, concluded that expansion of the lung is not completed at the first breath, but that it takes several days and that a certain degree of initial atelectasis is physiological for several days after birth. Areas of incompletely formed pulmonary tissue are frequently present in premature infants, they concluded, and this is not true atelectasis.

Weymuller, Bell and Krahulik[12] made roentgenographic studies of 25 normal babies during the first 14 days of life. In only one was there evidence of atelectasis and this disappeared after 24 hours. Farrell[4] took roentgenograms of 159 infants within 48 hours of birth, most of them on the first day. No atelectasis was found in any. He stated that roentgenographically all of the lungs were fully expanded by the time the roentgenograms were made. On the other hand, Smith[11] cited findings from the Boston Lying-In Hospital that 18 per cent of the infants showed unexpanded areas in the lungs by roentgenography.

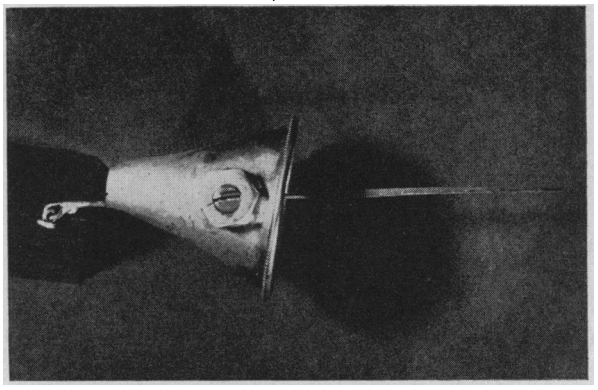

Figure 1.—Instrument for measuring the cohesive properties of nasal mucus. The narrow metal arm is mounted upon watch jewels to reduce friction. It balances without weights. The small silver plate suspended from the forward end is 10 square millimeters in area. In use, this plate is pressed into the mucous film on the floor of the nose and an appropriate weight is hung on the other end of the arm and moved back until the plate lifts free. The amount of pull required is then calculated from the weight used and the comparative lengths of the lever arms.

House and Owens[7] bronchoscopically examined 23 babies who had atelectasis. It is striking that 80 per cent of these babies were premature.

Gottschalk[5] reported a study on the results of premedication administered to mothers. He made a total of 68 records of the respirations in 40 infants during the first hour of life. The earliest was seven minutes after birth. Some of the mothers had received Demerol® and hyoscine and others had not. The study definitely indicated that Demerol and hyoscine, no matter when administered, exert no effect on the respiration of the newborn infant.

VISCOSITY OF RESPIRATORY MUCUS

In connection with these problems, the previously mentioned group of six physicians is making several studies upon which only a preliminary report, giving a few points, can be made at this time. The first concerns the viscosity of respiratory mucus. Measurements were made on five volunteers, two of whom were used on two different occasions.

Technique: An instrument (Figure 1) was devised for measuring the viscosity of respiratory mucus in the floor of the nose in situ. It consists essentially of a small silver plate, 10 square mm. in area, suspended at one end of a very light metal balance arm. This is mounted in an ear speculum on watch jewels at the fulcrum. In making the measurements, the little polished silver plate is pressed against the mucus on the floor of the nose and a measured weight moved out along the other arm of the balance rod until the silver plate lifts out of the mucus. The method is not entirely exact because a time element is involved just before the silver plate pulls free from the mucus. Nevertheless, an approximate

TABLE 1.—*The Effect of Atropine on the Viscosity of Respiratory Mucus*

Number of Readings	Subject	Milligrams per Square Millimeter of Resistance	Percentage of Increase
27	Control group	9.2 (avg.)	
33	After atropine, gr. 1/150th	12.4	34
26	After atropine, gr. 1/100th or gr. 1/75th	17.7	92
59	All those receiving atropine	14.9	62

measurement is obtained which can be repeated with reasonable consistency. The resistance measured is not that due to viscosity alone but is the resultant of several factors, among which are viscosity, surface tension, the stickiness or mucilaginous property, and perhaps also the Johansson phenomenon (Table 1).

The average of 27 control readings, before the administration of atropine, measured 9.2 mg. per square mm. of resistance. After the administration of 0.4 mg. of atropine, 33 readings averaged 12.4 mg., or an increase of 34 per cent. Twenty-six readings, after 0.6 mg. or 0.8 mg. of atropine, gave an average reading of 17.7 mg., or an increase of 92 per cent above the controls. Altogether, the 59 measurements, after the administration of atropine, averaged a resistance of 14.9 mg. per square mm. or 62 per cent above that of the controls. This indicates that the cohesiveness of the respiratory mucus can actually be increased by means of atropine.

EXPANSION OF LUNGS IN NEWBORN RABBITS

The next study was designed to measure the air pressure required to open the lungs in newborn rabbits and the effects of scopolamine and atropine upon the resistance found. Thirty-one fetuses, which were sacrificed immediately, before they had breathed, were used in this study.

Technique: The gestation period of a rabbit is said to be 32 days. The females were placed with a male 30 days before the experiment was made. On the 30th day of gestation, and, in one instance, on the 31st, the females were sacrificed and the fetuses delivered as rapidly as possible by abdominal section. The whole litter can readily be delivered in about two minutes. As quickly as the fetuses were delivered, those to be used in this study were sacrificed by sudden trauma while they were still within the amnionic sac before they had attempted to breathe. The entire respiratory tract, including the heart, was removed intact from each fetus, dissecting from below upward. All of the tracheas contained fluid and some contained blood. All were aspirated and then cannulated. The cannula was attached to a water manometer. When scopolamine or atropine was administered to the mother rabbits, it was given by hypodermic injection one hour previous to sacrificing them. The dose of scopolamine used was 0.4 mg. and of atropine either 0.1 or 0.2 mg.

Measurements were made on eight fetuses to determine the amount of air pressure necessary to inflate the lungs. It was found on these eight that "fully inflated" was an inexact state and a definite end-point of some kind would have to be established before the results could be depended upon. Several end-points were tried, but the one finally selected was as follows: The entire lung specimen, including the cannula in the larynx, was sunk in 20 mm. of water. Pressure was then made by means of either a glass or rubber syringe through a "Y" tube, which was connected both to the lung specimen and to the manometer. A reading was taken at that point when the entire lung specimen just barely floated free from the bottom of the basin.

Many of the lung specimens did not inflate smoothly or uniformly. In many, different portions inflated suddenly and at irregular intervals, causing jerky movements in the specimen as pressure was increased. This sudden inflation of some parts was so pronounced in several that pinging sounds were made against the bottom of the metal pan in which they lay.

Results: 108 determinations were made on 31 fetuses (Table 2). The average pressure required for inflating the lungs more or less completely on the first eight, before a definite end-point was established, was 220 mm. of water. Eleven measurements were made on seven specimens after the described end-point had been established, with the heart still contained within the specimen. The average result was 206 mm. of water. In the remaining specimens, the heart was excised. Twenty-four determinations on five specimens, with the previously described end-point, after the heart had been excised, indicated the average pressure required to float the lungs was 183 mm. of water. Forty-three determinations were made on eight specimens after the administration of atropine to the mother. The average of these 43 readings was 191 mm. of water, a rise of only eight points. Twelve determinations were made on three specimens after the administration of scopolamine; the average pressure required to float the lungs was 181 mm., or 2 mm. less than for the controls. In these few determinations, there was no indication that the administration of atropine or scopolamine increased the pressure which was necessary to open the lungs in the fetuses. These findings do not correspond with those found on the volunteers. Many reasons for these apparent discrepancies come to mind.*

POSITIONS OF THORACIC ORGANS IN THE FETUS

It was noted in making the dissection for removal of the lungs in these animals that the lungs occupied only a small part of the space in the thorax after the

*Perhaps the rabbits are not greatly affected by these drugs; perhaps the scopolamine does not reach the fetus, at least in one hour; maybe the fluid in the bronchial tree prevents an increase in cohesiveness of the mucus; probably the number of measurements made was too low to be statistically significant; although both sets of measurements were made in the respiratory tract, conditions are very different in the anterior portion of the nose from those in bronchioles and alveoli; the two species are very different, as are the physiological ages.

TABLE 2.—*Air Pressure Required to Open the Lungs in Newborn Rabbits and the Effects of Scopolamine and Atropine Upon the Resistance Found*

Number of Measurements	Number of Fetuses	Subject	Mm. of H_2O
8	8	Controls without end-points + heart	220
11	7	Controls with end-point + heart	206
24	5	Controls with end-point, without heart	183
43	8	After atropine	191
12	3	After scopolamine	181
Total: 108	31		

latter had been opened. It was observed that the lungs were in contact with the diaphragm and with the chest wall before air was admitted, but, as soon as air gained access to the pleural space, the lungs collapsed into a comparatively small portion of the space within the thorax. The question naturally arose as to what occupied the remaining portion of the space. Since the pleural cavity was entirely closed and since the bronchial tree was open to the amniotic fluid, it seemed that there could be only one answer, namely, that there was fluid in the lungs which was squeezed out as the elastic lungs collapsed.

Two preparations were made to demonstrate the fluid. The trachea and larynx in one fetus were exposed before the thorax was opened and a glass slide slipped under the trachea. The trachea was then carefully dried and cut across on the glass slide. The thorax was then opened and it was observed that the lungs collapsed as usual. However, there was no flow of fluid out of the trachea onto the slide. In a second specimen, the trachea was exposed and tied off and the entire respiratory tract, with the heart attached, was removed from the thorax. The entire specimen was then carefully dried and laid upon a glass slide and the trachea opened. Again there was no flow of fluid from the end of the trachea, nor did the lungs collapse. This seemed odd, but, after a little further study, the reason was found and it led to another point of interest.

It was found that the lungs did not actually collapse upon opening the thorax; instead, the thorax enlarged. The fetus before delivery was in a position of ventroflexion, which forced the liver high into the thorax, where it occupied most of the space within the thoracic cage. When the animal was straightened out, it was found that the diameter of the thorax decreased as the liver was drawn caudally. In one animal, the girth of the thorax in the fetal position measured 79 mm.; when it had been straightened out, the girth was 75 mm. In a second, the thorax measured 79 mm. in the fetal position and 74.5 mm. after straightening. In a third, the girth of the thorax was 81 mm. in the fetal position and 77.5 after straightening. The reduction in girth is undoubtedly due to atmospheric pressure acting upon the outside of the thorax. As soon as air is admitted to the pleural cavity, the ribs tend to spring out, enlarging the cavity again.

This point may be a factor in helping the fetus to get its first breath. These little animals go into a position of opisthotonos in taking the first gasping breath. The human baby does something similar. It may be that in stretching out in this way, a negative pressure develops within the thorax, which is an aid in expanding the lungs with the first breath.

EFFECT OF CHILLING

An accidental finding, during work on one litter of rabbits, seemed to bear out the idea of Bell. Rabbit 6 contained seven living fetuses, four of which were sacrificed and three of which were allowed to remain alive for a time. They were maintained in a room at 40° F. The first of the latter group, which was very vigorous, was sacrificed after an hour; the lungs appeared to be fully inflated and floated high. The other two became rapidly weaker and at the end of 105 minutes did not move unless stimulated. When the respiratory tracts in these two were removed, it was found that the lungs in both were almost completely atelectatic. They looked the same as did the lungs of those that had not breathed at all. Both floated, but so heavily that they barely broke the surface of the water. Following up this lead, all of the fetuses from the next animal used were allowed to live. This was at a later date and the weather was considerably warmer, the temperature of the room being high enough so that one could work comfortably in shirtsleeves.

Motion picture equipment was set up for the purpose of recording the anticipated progressive atelectasis. It was intended to expose the fetuses, photographing them at intervals to show progressive weakness from chilling, and then to sacrifice them serially and demonstrate the progressive atelectasis. The first four were sacrificed at intervals from 25 minutes to four hours after delivery; in none of these was there atelectasis. The remainder were placed in a temperature estimated to be about 40° F. After five hours atelectasis was not present in two animals which died. The remaining two were very feeble 17 hours later and at postmortem one of them was found to show patchy atelectasis that was proven by microscopic examination. In the other, the lungs seemed fully expanded. No conclusion can be drawn from these three instances of atelectasis. Perhaps chilling and progressive enfeeblement were factors. It is possible that in these three instances the lungs did not expand immediately after birth. However, the animals did not look or act any different from their litter mates in which the lungs were fully expanded.

EFFECT OF PREMATURITY

An observation was made, also by accident, on the effect of prematurity. It was intended in all of these studies to sacrifice the females on the 30th day of gestation. With the first few animals, great care

was taken that the female should not be with the male more than a few hours. As conception usually took place in so short a time, it was assumed that it would in all cases and the female therefore was not always removed promptly in the later stages of the study. Consequently, there were two cases in which conception must have been delayed because the fetuses were somewhat premature. The fetuses from the first of these animals seemed to be near term and, when removed from the amnionic sac, breathed and crawled around, but with less vigor than those born at term. They were unable, however, to free themselves from the amnionic sac and it seemed to be much more difficult for them to get respiration established. In the term animals, the first breath or two was gasping in nature with all of the accessory muscles of respiration brought into action, but, after a few gasps, breathing seemed to be easy. In this first litter of premature rabbits, there were many gasping attempts before respiration was established.

The second of these litters was still more premature. These animals made no attempt to get out of the amnionic sac. When removed they lived for about a half hour and respiration was not established. Gasping attempts at inspiration occurred at intervals of 20 seconds to two minutes. The last gasp was just as labored as the first.

ROENTGENOGRAPHIC STUDIES

Two series of x-ray studies were made and another is under way. In the first series, one roentgenogram was made of each infant within the first 24 hours after birth. In 118 of these the roentgenologists diagnosed atelectasis in 40 or 34 per cent (Table 3). In the second series, each infant was roentgenographed on each of the first three days after birth; 18, or about half of these, showed atelectasis. In most the atelectasis was less on the second and third days than on the first, but in four there was more indication of atelectasis on the second or third days than on the first. These findings are similar to those reported by others and seem to indicate definitely that some degree of atelectasis after birth is normal. All such studies are suspect unless the roentgenograms have been taken at the same phase in respiration. In the series here reported they were not so taken. It is said that there is very little residual air in the lungs of a newborn infant and the aeration between the height of inspiration and forced expiration is pronounced.

The discrepancies noted in the various series of roentgenographic studies are probably due to differences in the criteria of diagnosis. In the group making the present study there was disagreement as to what constituted atelectasis.

A third series has been started, designed to demonstrate the progressive aeration in the first few minutes of life. In this study, exposures are made in series a few minutes apart, beginning before the first breath if possible. The aeration develops rapidly, but is by no means complete after the first 10 or 15 minutes. Among other points of interest are the changes in position of the ribs and of the heart. The ribs appear somewhat compressed before the first breath and, before long, assume a more or less horizontal position, suggesting a change comparable to that found in the newly delivered rabbits after they have been straightened from a fetal position. Another thing of interest is the change in position of the heart. Before the first inspiration, the heart outline is not distinguishable. As soon as aeration begins, the heart shadow appears large and globular, filling the apex of the thorax. After a day or two, or even after a few hours, it is much smaller, has assumed the familiar boot shape and is sharply outlined.

TABLE 3.—*Roentgenographic Findings, First Series, in the Lungs of 118 Normal Newborns. Roentgenograms Taken During the First 24 Hours of Life*

Number of New-Borns X-Rayed	Subject	No Atelectasis	Atelectasis (some degree)
58	After Demerol + scopolamine	36 (62%)	22 (38%)
48	After Demerol alone	33 (69%)	15 (31%)
12	No medication	9 (75%)	3 (25%)
Total: 118		78 (66%)	40 (34%)

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REFERENCES

1. Beck, Alfred C.: Obstetrician's responsibility for hazards of first few days of life with special reference to anoxia and prematurity, Am. J. Obst. and Gynec., 51:173-183 (Feb.), 1946.

2. Bell, E. T.: Personal communication.

3. Farber, Sidney, and Wilson, James L.: Atelectasis of newborn; study and critical review, Am. J. Dis. Child., 46: 572-589 (Sept.), 1933.

4. Farrell, J. T.: Roentgen appearance of chest of newborn infant, Am. J. Roentgenol., 24:140, 146 (Aug.), 1930.

5. Gottschalk, Robert H.: Respiration during the first hour of life, Am. J. Obst. and Gynec., 52:651-656 (Oct.), 1946.

6. Gruenwald, Peter: Surface tension as factor in resistance of neonatal lungs in aeration, Am. J. Obst. and Gynec., 53:996-1007 (June), 1947.

7. House, H. P., and Owens, H.: Atelectasis of newborn: Treatment by bronchoscopic drainage, J. Pediat., 28:207-209 (Feb.), 1946.

8. Labate, John S.: Study of causes of fetal and neonatal mortality on obstetric service of Bellevue Hospital, Am. J. Obst. and Gynec., 54:188-200 (Aug.), 1947.

9. Potter, Edith L., and Adair, Fred L.: Fetal and Neofetal Death, Chicago, University of Chicago Press (March), 1940, p. 41, 109-110.

10. Potter, Edith L., and Dieckmann, Wm. J.: Fetal and infant mortality for the Chicago Lying-In Hospital: 1941 to 1946, Am. J. Obst. and Gynec., 56:593-597 (Sept.), 1948.

11. Smith, Clement A.: The Physiology of the Newborn Infant, Charles C. Thomas, 1945, p. 58, p. 46.

12. Weymuller, C. A., Bell, A. L. L., and Krahulik, L.: Roentgenographic changes in thorax of normal newborn babies, Am. J. Dis. Child., 35:837-855 (May), 1928.

13. Wilson, J. L., and Farber, Sidney: Pathogenesis of atelectasis of newborn, Am. Dis. Child., 46:590-603 (Sept.), 1933.

14. Zettelman, Henry J.: Initial fetal atelectasis, Am. J. Obst. and Gynec., 51:241-243 (Feb.), 1946.